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Consumer Demand for Rice Grain Quality and Returns to Research for Quality Improvement in Southeast Asia

Laurian J. Unnevehr

Abundant world rice supply has led to renewed interest in improving grain quality of modern rice varieties. Implicit prices of grain characteristics are estimated for Thailand, Indonesia, and the Philippines. These prices are used to evaluate rice-breeding goals and to estimate returns to research for quality improvement. Results indicate that the past focus on physical quality improvement was appropriate, and future welfare gains are possible from chemical quality improvement. Returns to quality improvement are substantial and indicate underinvestment in this type of research.

Key words: demand for characteristics, grain quality, hedonic prices, returns to research, rice, Southeast Asia.

As Asian rice production grew faster than population from 1965 to 1980, the real price of rice declined in world markets and several Asian countries (Flinn and Unnevehr). Greater supply and falling prices have increased concern for rice grain quality improvement in national and international research programs in tropical Asia (Khush). In this article, the consumer goods characteristics model developed by Ladd and Suvannunt is used to estimate the implicit prices of rice grain quality characteristics in Thailand, Indonesia, and the Philippines. These estimated implicit prices answer three questions: (a) Do observed consumer preferences correspond to measures of quality used to screen material in breeding programs? (b) Are consumer preferences similar across countries so that quality improvement can be undertaken at the international level? (c) What are the returns to re-

search for quality improvement? Although many studies have estimated the returns to raising yields of agricultural commodities (see Norton and Davis for a review), there have been no previous estimates of the returns to quality improvement.

A Model of Consumer Demand for Goods Characteristics

The model of consumer demand for goods characteristics is adapted from Ladd and Suvannunt. Products are demanded for the utility they provide, which in turn is a function of the characteristics of the product. It can be shown that (Ladd and Suvannunt, p. 505)

$$(1) \quad P_i = \sum_{j=1}^m (dX_{oj}/dq_i) [(dU/dX_{oj})/(dU/dE)],$$

where P_i is market price of product i ; X_{oj} , total amount of the m th product characteristic provided by consumption of all goods; q_i , amount consumed of product i ; and E , income.

The marginal yield of the j th product characteristic by the i th product is dX_{oj}/dq_i . The marginal utility of the j th product characteristic is dU/dX_{oj} , and dU/dE is the marginal utility of income. Therefore, the ratio in brackets is the marginal rate of substitution between income and the j th product characteristic. As

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expenditure is assumed to equal income, the bracketed term is also the marginal implicit price of the j th characteristic (Ladd and Suvannunt, p. 505). Equation (1) states that the product price paid by the consumer equals the sums of the marginal values of the product's characteristics. Each value is equal to the quantity of the characteristic obtained from a marginal unit of the product multiplied times the marginal implicit price of the characteristic.

As yield of most product characteristics is constant for each unit of a product, dX_{oj}/dq_i is assumed to equal a constant X_{ij} . Furthermore, the marginal implicit price is also assumed constant over the range of X_{ij} observed and is represented by P_{ij} . Therefore, equation (7) for a particular product i , such as rice, becomes

$$(2) \quad P_R = \sum_{j=1}^m X_{Rj} P_{Rj} + u,$$

where P_R is the price of rice and u is random error. The dependent variable, P_R , will vary for different grades of rice. The independent variables, the X_{Rj} 's, should explain variance in the rice price and the parameter estimates (P_{Rj} 's) give the implicit values of grain characteristics. The usual assumptions regarding u are made, i.e., mean equal to zero, constant variance, and serial independence.

Estimates of implicit prices can be used to estimate the consumer surplus gains from breeding better taste characteristics into rice. Introduction of a new modern rice variety (MV) with better quality is equivalent to altering one or more of the X_{Rj} 's, i.e., the amount of a characteristic in each unit of rice is altered. Ladd and Suvannunt (p. 506) have shown that this innovation will change the amount (q_i) of the commodity consumed if all P_i 's and other X_{ij} 's are held constant. Quality improvement therefore leads to a rightward shift of the ordinary demand curve for rice MVs from DD to D^*D^* (figure 1). This increase in quantity demanded is equivalent to an increase in consumer utility obtained from each unit of rice. From equation (2), this gain is equal to

$$(3) \quad G = \sum_{j=1}^m (X^*_{Rj} - X_{Rj}) P_{Rj},$$

where G is consumer surplus gain per unit rice consumed; P_{Rj} , implicit price of characteristic j ; X^*_{Rj} , new value of characteristic j obtained from one unit; and X_{Rj} , old value of character-

Figure 1. Consumer surplus gains from quality improvement

istic j obtained from one unit. It is assumed that the implicit price P_{Rj} does not vary for the change in X_{Rj} .

The total consumer surplus gain will depend on whether P_R changes. Ladd and Suvannunt's model is derived from assumptions concerning individual consumer behavior. At the market level, each P_{Rj} represents both the marginal costs of producing a rice variety with a particular level of X_{Rj} as well as the marginal utility of X_{Rj} to the consumer (Rosen). In order to measure the net social welfare gains from improved quality, some simplifying assumptions about supply are made. The new higher-quality MV is assumed to have the same costs of production as older MVs. The quality improvements considered below can be obtained without any reduction in yield, so this assumption is quite realistic. Further, MV supply is assumed to be infinitely elastic over the range of the increase in quantity demanded. The demand increase can be estimated from the following:¹

$$(4) \quad \epsilon_{q_R, X_{Rj}} = - \frac{P_{Rj} X_{Rj}}{P_R} \epsilon^*_{q_R, P_R},$$

where $\epsilon_{q_R, X_{Rj}}$ is elasticity of quantity of rice consumed with respect to X_{Rj} , and $\epsilon^*_{q_R, P_R}$ is income compensated own-price elasticity of

¹ From Ladd and Suvannunt (p. 506), the increase in consumption will be equal to:

$$dq_R/dX_{Rj} = [(-1/dU/dE)(dU/dX_{Rj})](dq_R/dP_R)^*,$$

where dq_R/dP_R^* is income compensated own-price substitution effect. From equations 1 and 2, $-P_{Rj}$ can be substituted for the term in brackets. If both sides of the equation are then multiplied by $(X_{Rj}/q_R)(P_R/q_R)$, equation (11) is obtained.

rice. The change in consumption for the quality improvements considered below will be 6% to 14%. This increase in quantity demanded could easily be supplied by a slight increase in adoption of higher-yielding MVs, perhaps by farmers who grow traditional varieties (TVs) for home consumption because of their own taste preferences. As the increase in quantity demanded is small, the assumption of no change in P_R seems reasonable.

Under these assumptions, there is no change in producer surplus and there is a consumer surplus gain equal to the shaded area in figure 1. This area is estimated by the following:

$$(5) \quad CS = q_R G + \frac{1}{2} (q_R - q_R) G$$

where CS is total consumer surplus gain, and q^*_R is quantity of MV rice consumed after the quality change. The present value of this consumer surplus gain from future consumption can be compared to the present value of past research costs to develop the new variety in order to estimate the returns to research for quality improvement.

Data

The data are obtained from rice samples collected in the retail markets of the Philippines, Indonesia, and Thailand.² Samples were taken of each grade of rice offered by randomly chosen retailers, and price and advertised variety name were recorded for each sample. The retail markets were chosen to reflect the full range of preferences displayed by different income classes. All samples were collected within one week in order to minimize price variance due to factors other than quality.

The samples were analyzed in the Cereal Chemistry laboratory of the International Rice Research Institute (IRRI) for physical and chemical characteristics.³ The expected rela-

Table 1. Rice Grain Quality Characteristics

Grain Characteristic (measure) ^a	Expected Relationship to Price
Physical	
Whiteness (% of pure white)	+
Broken (% of grains)	-
Shape (ratio length/width)	+
Chalkiness (proportion of grain)	-
Chemical	
Amylose (%)	-
Gel consistency (mm)	+
Gelatinization temperature (Alkali spread)	-
Fragrance (0-1 Dummy)	+

^a Full definitions of characteristic measures are found in footnote 3.

tionship of characteristics to rice price (table 1) is based on observed world market demand and consumer taste panel tests (see Juliano for a summary). IRRI screens rice varieties for quality based on these expected preferences.

Physical characteristics include whiteness, broken grains, shape, and chalkiness. Whiteness (polish) and presence of broken indicate the quality of milling. Shape, the ratio of grain length to width, and chalky areas in the grain are varietal characteristics. Consumers should prefer white, long slender rice with few broken and little chalkiness.

The chemical characteristics, amylose content, gelatinization temperature, gel consistency, and fragrance, affect cooking and eating quality. Amylose content is the most important chemical characteristic and determines the hardness of cooked rice. Many TVs have intermediate amylose and cook moist and tender, while most MVs have high amylose content and harden after cooling. As a soft texture is preferred, price should be inversely related to amylose content. Gel con-

² The markets were Metro Manila (Nepa-Q), Baguio, and Calamba in the Philippines; Pasar Senen, Djatinegara, Tanah Abang, and Majestik in Jakarta, Indonesia, and the Farmer's Organization Market and Weekend Market in Bangkok, Thailand. Samples were collected in June 1983, November 1983, and March 1984 in the Philippines, Thailand, and Indonesia, respectively. All prices converted to US\$ with exchange rate current at the time samples were taken.

³ Whiteness is measured by a Kett whiteness meter, an optical instrument. The scale is from 0 to 100, with 100 indicating pure white magnesium oxide powder. Chalkiness is measured on the

samples by the Rice Quality Laboratory by a visual rating of the chalky proportion of the grain. The scale is 1 (less than 10%), 5 (10 to 20%) and 9 (more than 20% chalkiness), so higher numbers indicate more chalky area. Percent broken is determined by grain sizing and weighing broken grain in a 100-gram subsample. Length and width in millimeters are measured for ten whole grains. The percent amylose content is evaluated using the simplified iodine colorimetric procedure. Gelatinization temperature is measured by the alkali spreading value. This is the extent of disintegration of milled rice soaked in a 1.7% potassium hydroxide solution for 23 hours at 30°C. A high rating indicates more disintegration and a low gelatinization temperature. Gel consistency is measured by the length of cold milled rice paste in a test tube in horizontal position (unreplicated 90 and 100 mg/2 ml 0.2 N KOH). A higher number indicates a softer consistency. Mean of 90 and 100 mg rice data is presented.

sistency is another measure of texture, and a higher value indicates softer texture. Price should be positively correlated with gel consistency. Gelatinization temperature (GT) determines the time required for cooking. Rices with intermediate GT are expected to be preferred over those with low GT, because most TVs have intermediate GT. As the alkali spread measure is inversely correlated with GT, this variable should have a negative implicit price. Fragrance is a special characteristic of some traditional varieties, and it usually commands a price premium. Its presence or absence is indicated by a 0–1 dummy variable.

Results

The range of choice of characteristic values available to consumers in each country depends on the rice varieties grown there. In the Philippines, MVs were planted on 85% of rice area in 1982 (Philippine Ministry of Agriculture). These are primarily IRRI MVs that have high (>25%) amylose content. The Philippine samples reflect national statistics; they were 91% MVs and had a high average amylose content of 28% (table 2).

MVs are also widely adopted in Indonesia, where they covered 60% of rice area in 1980 (Herd and Capule). Many of the MVs grown are locally developed varieties that have intermediate (20–25) amylose content, rather than

the high amylose content of IRRI varieties. The samples collected in Indonesia were about half MVs and half TVs. The MV samples had intermediate amylose so the sample average amylose content of 23% is much lower than in the Philippines (table 2). Many of the TV samples were local varieties that have short, chalky grains. Thus, Indonesian samples on average had a bolder shape and more chalkiness than Philippine samples (table 2).

Thailand is the world's largest rice exporter, and world market preferences for long translucent grains and good milling quality strongly influence the domestic market. Because IRRI varieties have grain shorter than 7.0 mm, they are not released directly in Thailand. Rather, Thai scientists have used IRRI varieties as parents in crosses to develop semidwarf varieties with the physical grain quality demanded by the world market. MVs released in Thailand were planted on only about 10% of cultivated area in the late 1970s (Herd and Capule), because they are not suited to the rainfed conditions there. The samples collected in Thai markets had a lower percentage broken and longer grains than in the other two countries (table 2).⁴ The samples were all TVs and on average they have the preferred characteristic of intermediate amylose content. Many of the Thai samples were also fragrant.

Estimates of implicit prices of grain quality characteristics for the three countries are presented in table 3.⁵ The implicit price represents the change in the rice price for a one-unit change in the characteristic. The quality attributes included explain a large proportion of price variation in all three countries, indicating that laboratory measures provide good in-

Table 2. Average Characteristics of Rice Samples

	Philippines	Indonesia	Thailand
Price (US¢/kg)	31.1 (4.3) ^a	43.5 (7.1)	34.7 (5.0)
Whiteness	42.4 (2.7)	39.4 (2.5)	40.5 (2.7)
Broken	42.5 (10.7)	37.7 (11.3)	16.3 (15.4)
Chalkiness	3.9 (2.0)	8.0 (1.8)	4.1 (2.2)
Shape	3.2 (0.2)	2.5 (0.3)	3.5 (0.3)
Amylose	27.8 (2.4)	23.4 (2.3)	23.6 (4.2)
Gel consistency	41.1 (10.2)	46.8 (8.3)	56.6 (14.6)
Gelatinization temperature	5.7 (0.6)	5.5 (0.7)	5.1 (0.8)
% Fragrant	5.6	11.9	31.4
No. samples	107	118	86

^a Standard deviations are in parentheses.

⁴ Raw paddy only yields milled rice with 60%–80% whole grains. In order to sell rice with a greater percentage of whole grains, rice is sorted into head rice and broken at the mill in Thailand. Broken are used in specialty dishes or animal feeds.

⁵ The diagnostic technique of Belsley, Kuh, and Welsch indicated that estimates of whiteness, shape, and amylose are degraded in all three regressions. The degraded regression estimates remain significant or insignificant, however, regardless of the regression specification. Thus the OLS estimates provide reasonable indicators of the relative importance of different characteristics. The implicit price of amylose in the Philippines is the only degraded parameter estimate used in the returns to research calculations, and the lower estimate used (see below) provides conservative estimates of returns. The Durbin-Watson statistic of 1.55 in the Philippine regression indicates that first-order autocorrelation in the residuals is statistically significant at the 5% level. GLS parameter estimates corrected for first-order autocorrelation show no difference in significance levels from OLS estimates. Therefore the OLS estimates are reported.

Table 3. Regression Estimates of Implicit Prices for Grain Quality Characteristics in Three Southeast Asian Countries (dependent variable is price in US¢/kg)

Country/ Regression	No. Samples	Intercept	White	Broken	Chalky	Shape	Amylose	Gel- Consis- tency	Gelatini- zation Temper- ature	Fragrance	R ²	Durbin- Watson
Philippines	107	35.16 (4.38) ^a	0.34 (3.18)	-0.12 (-5.10)	-0.38 (-3.17)	2.85 (1.68)	-1.12 (-9.49)	-0.01 (-0.35)	1.94 (4.20)		.71	1.55
Indonesia	118	-0.19 (-0.02)	1.14 (5.39)	-0.18 (-4.58)	0.00 (0.00)	-4.68 (-2.31)	0.14 (0.53)	0.05 (0.96)	1.92 (2.26)	9.07 (6.71)	.64	1.77
Thailand	86	14.71 (2.62)	0.30 (3.47)	-0.15 (10.57)	-0.15 (-1.10)	2.47 (2.29)	-0.02 (-0.22)	0.02 (1.14)	-0.04 (-0.12)	5.89 (6.00)	.89	1.80

^a *t*-statistics are in parentheses.

dicators of consumer preferences. The signs and significance of characteristics vary among countries, however.

In the Philippines all characteristics are significant except gel consistency and shape (table 3, regression 1). The Philippine data did not have enough fragrant samples (6 out of 107) to measure accurately an implicit price for fragrance. Consumers show the expected preferences for physical quality and amylose content, but the implicit price of GT has an unexpected sign. In this sample of predominantly high amylose rices, amylose content alone explained over 50% of price variation. This result supports the hypothesis that high amylose content is the most important negative attribute to IRRI MVs.

Indonesian consumers also show a significant preference for better milling quality and, in particular, a very strong preference for white (well-polished) rice. Other physical quality preferences differ. Because Indonesian consumers prefer their local TVs that have short, chalky grains, there is a negative implicit price for shape and no significant negative price for chalkiness. As in the Philippines, the positive implicit price for GT in Indonesia indicates an unexpected preference for low GT. The implicit price of amylose content in Indonesia is not as large or significant as in the Philippines, perhaps because most Indonesian samples (101 out of 108) already have the preferred intermediate level of amylose content. Therefore consumers do not place any value on further reductions in amylose content.

The significance of milling quality characteristics and shape in Thailand reflects the importance of export demand. Fragrance is the only significant chemical characteristic. There is no significant price for lower GT in Thailand, although the Thai samples have a higher

average GT than samples in other countries. Thus only Thai consumers show the expected preference for intermediate GT.

In summary, preferences for good milling quality and fragrance are similar and have the expected sign in all countries, but preferences for shape and chemical attributes vary. Chalkiness and gel consistency do not seem to be particularly significant determinants of price in any country. The hypothesis concerning consumer preference for an intermediate GT needs review, as Philippine and Indonesian consumers show a significant preference for low GT.

The hypothesis that consumers prefer intermediate amylose is generally supported. The high amylose content of IRRI MVs in the Philippines is clearly not preferred. In Indonesia and Thailand most samples already have the preferred intermediate amylose content, so no significant value is observed for further reductions. The importance of intermediate amylose to Indonesian consumers is revealed indirectly by the efforts of local plant breeders to breed MVs with this characteristic. One intermediate amylose MV released in 1981 was so widely adopted in 1984 that very few high amylose rices were found in the market samples.

Returns to Research for Quality Improvement

The estimated implicit prices indicate that there are returns to plant breeding for two types of quality improvement at the international level. Improving potential head rice (whole grain) recovery, which is an inherited trait, has widespread benefits as consumers in all three countries prefer fewer broken grains. This type of improvement was seen in 1970 with the introduction of IR20, a variety with

potential head rice recovery of more than 60% of paddy. The earlier MVs, IR5, and IR8, have head rice recovery of only 36% to 40% of paddy.

Development of intermediate amylose rice varieties that have a wide range of acceptability in different agroclimatic environments would also benefit consumers in Southeast Asia. An intermediate amylose MV released in the 1960s, C4, was abandoned by farmers when it proved highly susceptible to insect pests. Cisadane, the intermediate amylose MV developed in Indonesia, is resistant to an important insect pest, but is not suitable for the Philippines because it is not resistant to a common rice disease there. IRRI would have a comparative advantage over national programs in incorporating multiple pest and disease resistance into an intermediate amylose variety. Such resistance would lower the production costs of the improved taste characteristic to the level of current IRRI MVs.

The consumer surplus benefits from quality improvement are estimated and compared with costs for three changes in quality; two actual changes in the past and one likely change in the future. The improvement in potential head rice recovery in IR20 and later varieties as compared with IR8 or IR5 had returns in the Philippines and Indonesia. Early MVs had already been adopted on 50% and 25% of Philippine and Indonesian rice area, respectively (Herdt and Capule; Salmon). Annual consumer surplus gains from better head rice recovery are estimated to be \$73 million in the Philippines and \$224 million in Indonesia (table 4). The costs of developing better head rice recovery are taken to be 15% of IRRI's budget from 1962, when the Institute opened, to 1969, when IR20 was released. Fifteen percent is an informal estimate of the proportion of research efforts devoted to grain quality (Khush, personal communication).⁶ Improvement of head rice recovery had an estimated benefit/cost ratio of 49 and an internal rate of return of 61% (table 5).

Reduction of amylose content is assumed to have the same value for Indonesian and Philippine consumers. The estimated implicit prices of amylose in the two countries suggest that

Table 4. Benefit Assumptions for Estimation of Returns to Research

	Philippines	Indonesia
Better Head Rice Recovery		
$P_{RJ}[X^*_{RJ} - X_{RJ}](\$/\text{kg})^a$	4.56	6.84
q_R (000 MT rice) ^b	1532	3059
$\epsilon q_R, X_{RJ}(\%)^c$	8	14
q_{R^*} (000 MT rice) ^d	1655	3487
CS (million \$) ^e	73	224
Less Amylose		
$P_{RJ}[X^*_{RJ} - X_{RJ}](\$/\text{kg})^f$	2.70	2.70
q_R (000 MT rice) ^g	4199	8083
$\epsilon q_R, X_{RJ}(\%)^c$	6	8
q_{R^*} (000 MT rice) ^d	4450	8730
CS (million \$) ^e	117	227

^a Implicit price estimate from table 3. Head rice recovery assumed to improve by 38%.

^b Consumption from MVs is 50% and 25% of average rice production 1967–71 in Philippines and Indonesia, respectively.

^c Estimated from equation (4) with own-price elasticity of rice consumption assumed equal to 1.16 in Indonesia (Timmer and Alderman) and 0.67 in the Philippines (Bouis).

^d This is $[1 + \epsilon q_R, X_{RJ}]q_R$.

^e This is estimated from equation (5).

^f See text for source of implicit price estimate. Decline in amylose content assumed from 28% to 23%.

^g Consumption from MVs is 85% and 40% of average production 1978–83 in Philippines and Indonesia, respectively.

P_{RJ} (the marginal utility of amylose) is not constant for a decline in amylose content from high (28) to intermediate (23). Therefore, use of the implicit price of -1.12ϕ per kilogram (kg) from table 3 for a one unit change in amylose would tend to overstate the consumer surplus gains. For this reason, the smaller implicit price estimate of -0.54ϕ per kg from a high amylose subsample in the Philippines is used to value the change in amylose content.

The introduction of an intermediate amylose MV with pest resistance in Indonesia in 1981 should have provided annual consumer surplus gains of \$227 million. The costs of development are taken to be the entire Indonesian research budget for irrigated rice from 1969 to 1981. It is difficult to separate the expenditures for grain quality alone, and quality has been an important breeding goal (Bernsten, Siwi, and Beachell). Even with these large costs, the internal rate of return is 37% (table 5).

IRRI has distributed MVs with intermediate amylose and multiple pest resistance to national programs, and some were likely to be released in 1985. If these MVs are widely adopted in the Philippines, annual consumer surplus gains will be \$117 million. The costs of

⁶ IRRI plant breeders estimate that 15% of program effort was devoted to quality. As other programs in IRRI support plant breeding, 15% of the total budget is used as the research cost estimate. This very conservative cost estimate is chosen so that returns will not be inflated.

Table 5. Returns to Research for Quality Improvement

	Benefit Cost Ratio ^a	Internal Rate of Return ^b (%)
Past		
Better head rice recovery ^c (Philippines & Indonesia, 1970)	49	61
Less Amylose ^d (Indonesia, 1981)	8	37
Future		
Less Amylose ^e (Philippines, 1985)	9	29

^a Full adoption of new variety on existing MV area assumed complete 5 years after introduction of new variety. Hence, consumer benefits start 5 years after date of improvement and last for 50 years. Discount rate of 12% used to obtain present values.

^b The discount rate at which present values of benefits and costs are equal.

^c Costs are 15% of the IRRI budget 1962–69.

^d Costs are Indonesian rice research budget for irrigated lowlands, 1969–81, from Salmon.

^e Costs are 15% of IRRI budget 1969–85.

quality improvement are taken to be 15% of the IRRI budget from 1970 to 1985, as efforts before 1970 were devoted to improvement of physical quality and the costs since 1970 can be attributed to improved cooking quality. The rate of return to less amylose in the Philippines is 29% (table 5). This is smaller than the rate of return in Indonesia because total MV consumption is smaller.

The estimated returns to research demonstrate that IRRI's past focus on improving physical quality was appropriate because there are widespread, high returns to such improvement. Current efforts to improve cooking quality through reducing amylose content could have substantial returns in the Philippines alone. It would also increase the range of good quality MVs available to other countries with similar preferences. This has high potential returns, as demonstrated by the large hypothetical return to better quality local MVs in Indonesia.

Conclusions

This paper extends application of the consumer goods characteristics model to evaluation of the returns to agricultural research. Es-

timates of consumer demand for rice grain quality in Southeast Asia show that the measures used to screen for quality in tropical rice-breeding programs are good indicators of consumer preferences. Demand for milling quality is similar in all countries, but demand for shape and certain chemical characteristics varies, indicating substantial scope for national programs to tailor varieties to local preferences. International rice research should provide plant materials with a diversity of grain characteristics to national programs. International rice breeding should focus on maintaining good potential milling quality and on reducing amylose content of future MVs.

The estimated returns to research for past and future improvements in these two quality characteristics are quite high. These large returns to quality in poor countries are consistent with the finding that even the very poor have more income elastic demand for food quality than for food quantity (Shah). The estimated returns to rice quality improvement are not as large as past returns of 84% to 87% to improvements in rice yields (Evenson and Flores, Scobie and Posada). But the returns to quality improvement are large enough to extend Akino and Hayami's finding that there is underinvestment in agricultural research. There is underinvestment in research to improve the quality of agricultural commodities, as well as in research to increase yields.

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